Candidate Determination for Computer Aided Detection of Colon Polyps

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ABSTRACT

Given a segmented CT scan data of the colon represented as a triangle mesh, our water-plane algorithm will detect polyp candidates. The water-plane method comprises of pouring water into a polyp protrusion from the outside of the colon and in raising the "water-plane" until it cannot be incremented any further without causing water leakage. The method starts at a vertex and uses average normal of all triangles adjacent to the starting vertex to generate the initial water-plane, which will make the starting vertex "wet" but leave its neighboring vertices "dry". The method will continue to wet neighboring vertices one by one and then their neighbors and so on until the water-plane cannot move any further without causing water leakage. The water-plane movement alternates between just raising the water level in completely convex regions and tilting about one or two anchor vertices that have neighbors that would get wet if the water level was raised any more. The final set of wet vertices is a cluster that is an initial polyp candidate. The water-plane method was compared against the current polyp candidate detection method in our Computer Aided Detection of Colon Polyps software pipeline, called the surface curvature method. It finds clusters of connected vertices that all exhibit elliptical curvature. The water-plane method showed multiple improvements in polyp candidate detection. It detected polyp candidates missed by the surface curvature method. It exhibited continuous polyp candidate regions instead of non-uniform or incomplete regions detected by the surface curvature method. And finally, it avoided some false positive detections reported by surface curvature method.

Keywords: Computer Aided Detection, Colon Polyp Candidate, Water-Plane Method, Polyp Segmentation, Virtual Colonoscopy

1. INTRODUCTION

Colorectal cancer is the third most common cancer worldwide and the second leading cause of cancer deaths in the United States. It is estimated that there will be 146,940 new cases diagnosed in the United States in 2004 and 56,730 deaths due to this disease.[1] Adenomatous polyps develop into colorectal cancer and early detection and removal of these polyps can reduce 90% of the incidences reported.[2] Virtual colonoscopy combines CT scans of the colon with a virtual 3D representation of the colon interior to allow a radiologist to detect polyps. Research efforts are improving the accuracy of virtual colonoscopy and it is considered a less invasive exam then optical colonoscopy. One such effort, CTCCAD, Computed-Tomography-Colonography-Computer-Aided-Detection is under development at NIH as an aid to a radiologist to improve early polyp detection.

The water-plane method will detect polyp candidates given a segmented CT scan data of the colon. The 3D representation of the colon wall consists of vertices (points), edges (lines), and triangles that join together to form a triangular mesh that generate the inner surface of the colon. Each vertex in the mesh is tested to see if it is a local protrusion from the colon wall. Each such vertex becomes a seed point for a cluster of vertices that cover an extended protruding region. All such clusters are considered polyp candidates and will undergo further processing in the CTCCAD software pipeline to determine according to several other criteria whether they match true polyps.

2. METHODOLOGY

Generally, polyps have a distinct shape such they are bulbous and elliptical formations protruding into the luminal colon space. Viewing the colon from the intraluminal space, a polyp's shape is nearly convex (despite minor irregularities

within a polyp surface). We designed a method for determining vertex clusters which demonstrated the polyp shape characteristic of "nearly convex" called the water-plane method.

The water-plane method comprises of pouring water into a polyp protrusion from the outside of the colon and in raising the "water-plane" until it cannot be incremented any further without causing water leakage.

Generally, all vertices above the water-plane are considered "dry", while all below the water-plane are "wet", illustrated in Fig. 1. The method starts at a vertex and uses spatial information on the vertex's neighbors to generate a water-plane.
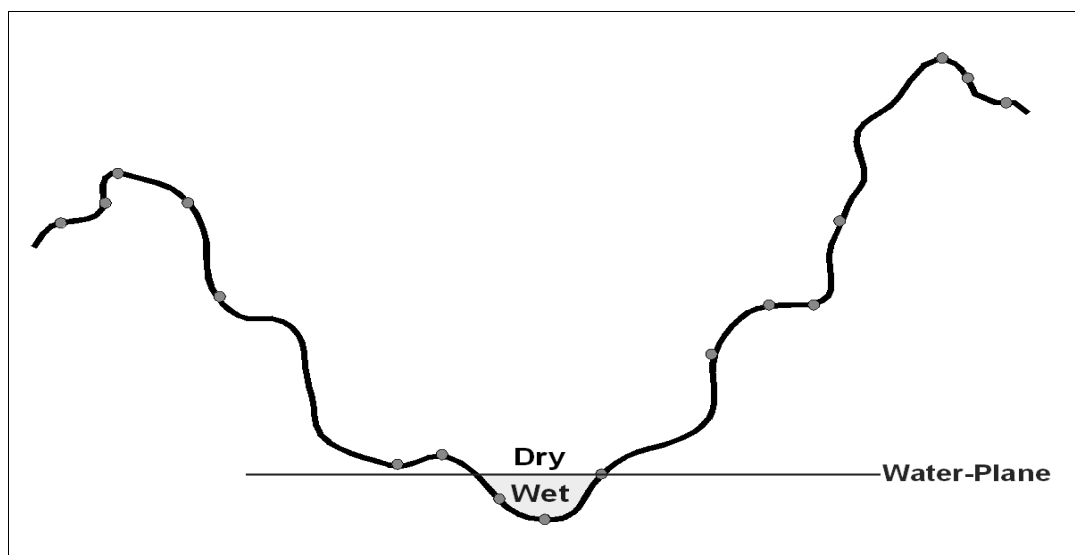

Figure 1: Illustration of "dry" and "wet" vertices on a polyp at the top of acolon cross section.

The water-plane will make the starting vertex "wet" but leave its neighboring vertices "dry". The algorithm's goal is to find the optimal water-plane such that the maximum number of vertices is on the "wet" side of the water-plane, defining the cluster of vertices that identify a polyp candidate. The method will continue to wet neighboring vertices one by one and then their neighbors and so on until the water-plane cannot move any further without causing water leakage. This method will iteratively test all vertices to see if a water-plane can be created and moved thusly defining wet vertex clusters that are the initial polyp candidates. All viable clusters will be colored.

The water-plane is first generated to be perpendicular to the average normal of all triangles adjacent to the starting, or seed vertex. All neighboring vertices are inserted in to the boundary set.

Once the initial water-plane is generated, it can be moved by four different modes. These modes are (1) increment altitude, (2) reorient plane with one anchor point, (3) reorient plane with two anchor points, and (4) no further movement. The movement is discrete, moving the plane just far enough to cause only a single boundary set vertex to get wet.

2.1 Mode 1: Increment water-plane's altitude

The water-plane method starts with mode 1, where the water-plane's advancement only increments its altitude without changing the water-plane's direction. In Fig, 2, our algorithm raises the water-plane to the vertex in the boundary set closest to the water-plane and adds its dry neighbors to the boundary set. The algorithm stays in this mode as long as each chosen vertex maintains the property that all of its neighbor vertices are on the dry side of the water-plane. Incrementing the plane will continue until a vertex is found that has a neighbor that is not on the dry side of the water-plane. Raising the water-plane higher would allow water to leak at that neighbor although it was not yet included in the cluster. Hence, we need to switch from mode 1 to mode 2.
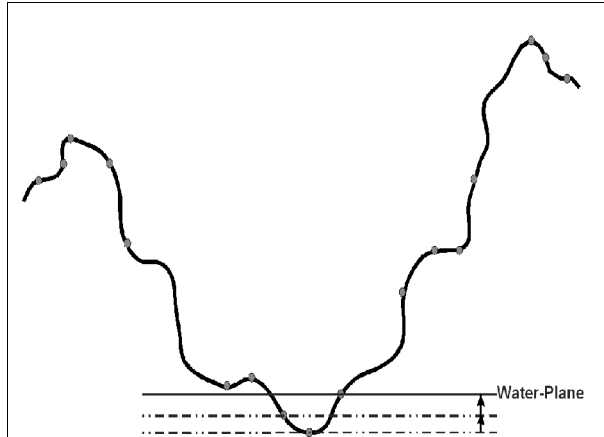

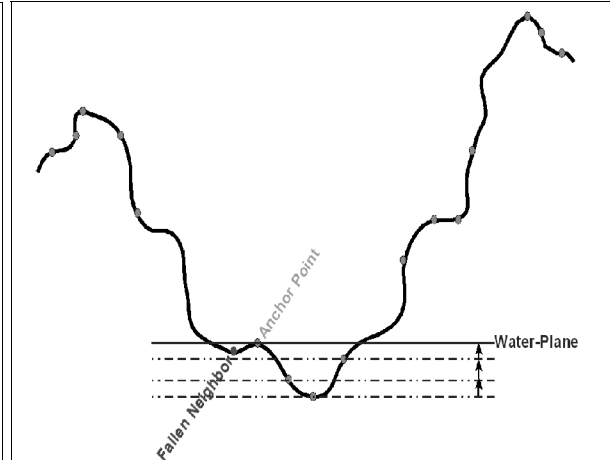*Figure 2: Mode 1 - Incrementing altitude only*

Figure 3:Mode 1 – Stop at fallen neighbor

2.2 Mode 2: Reorient water-plane with one anchor point

In mode 2, the water-plane's advancement will cause the plane's direction to change. This occurs when a previous change of the water-plane causes a chosen vertex's neighbor to become a "fallen" neighbor vertex, or a neighbor vertex that is not on the dry side of the water plane. A vertex is called an "anchor" point if it has a fallen neighbor vertex, shown in Fig. 3. The water-plane must not be raised above an anchor point to avoid leakage. The water-plane will anchor to that point, tilting the water-plane to recapture the fallen neighbor vertex.

The tilting is a rotation about an axis that lies in the water-plane, which pierces the anchor point and is perpendicular to the line segment from the anchor point to the fallen neighbor, shown in Fig. 4. This tilt direction minimizes the angle the water-plane will have to tilt such that the fallen neighbor vertex will be considered dry again. Next the plane is tilted just enough to wet the angle-wise closest boundary-set vertex. The tilting is repeated until the fallen vertex is again in the dry region or until a second fallen neighbor vertex is found. In the former case the algorithm will go back to mode 1, incrementing altitude only. In the latter case the algorithm will fall into mode 3, incrementing the water-plane with respect to two anchor points.

2.3 Mode 3: Reorient water-plane with two anchor points

If a second fallen neighbor vertex occurs, the water-plane must be reoriented with respect to two anchor points shown in Fig. 5. Therefore, the "tilt line" is the difference vector between the two anchor points, which now define the rotational axis the water-plane will use to reorient itself. When in this mode, depending on the recovery of fallen neighbor vertices, the algorithm can go into mode 1, 2, or remain in mode 3. If another vertex experiences a fallen neighbor vertex in addition to the two anchor points that are still trying to recover their fallen neighbor vertex vertices, then maximum re-orientation of the water-plane is achieved and the algorithm is now in mode 4, where no further movement of the water-plane is possible without causing leakage.
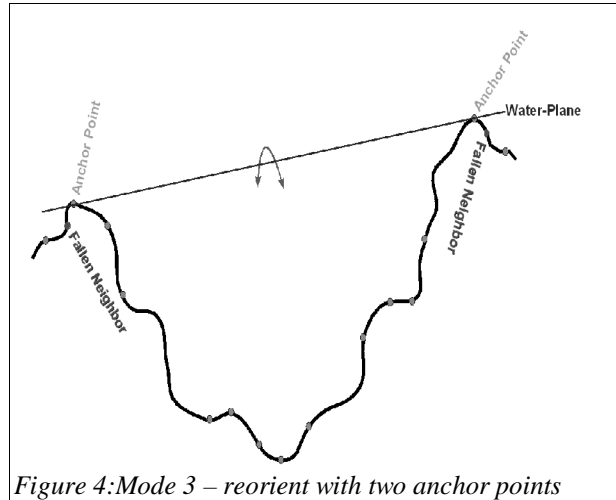

Figure 4:Mode 3 – reorient with two anchor points

2.4 Mode 4: No further movement

In mode 4, maximum re-orientation of the water-plane is achieved and all the vertices below the water-plane are considered the "wet cluster", depicted in Fig. 6, which is also a possible candidate. The wet cluster is assessed to see whether it is a good polyp candidate. It is considered good when it generates a water-plane that comprises of more than a threshold number of vertices. In our algorithm, we have defined the threshold as consisting of 20 or more vertices. These good clusters are our initial polyp candidates and will be further processed and possibly rejected by other segments of the CTCCAD software pipeline.
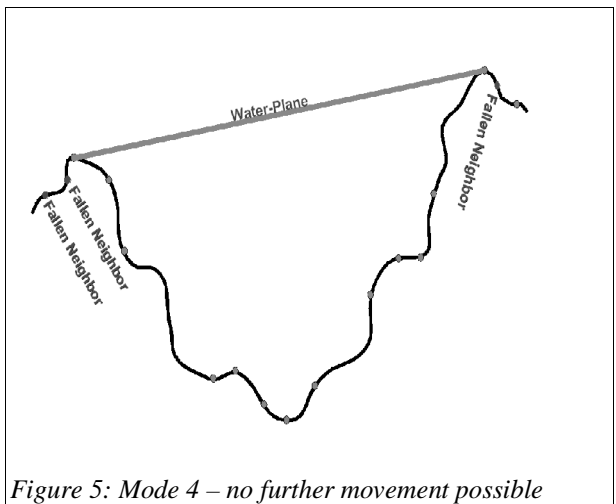

Figure 5: Mode 4 – no further movement possible

3. RESULTS

The water-plane method is compared against the surface curvature method, or the current polyp candidate detection method in the CTCCAD software pipeline, which finds clusters of connected vertices that all exhibit elliptical curvature. Both methods were tested on several CT scan images to compare their performance and accuracy of polyp candidate detection. The water-plane method showed improvement over the current method in several areas, Protrusions that were previously missed by the surface curvature method are now successfully detected, which is illustrated in Fig. 6.
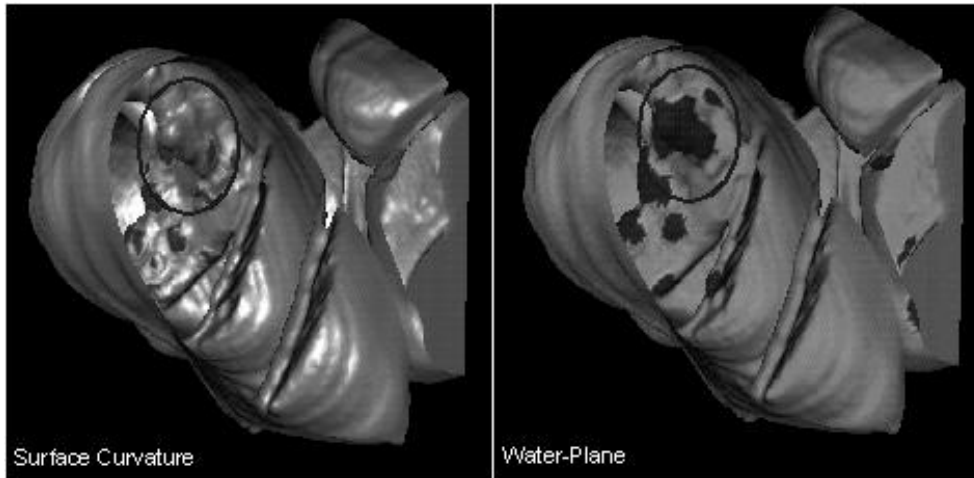

Figure 6:Detection of previously missed protrusions

Also, the water-plane method reports complete and continuous regions for polyp candidates, illustrated in Fig. 7.
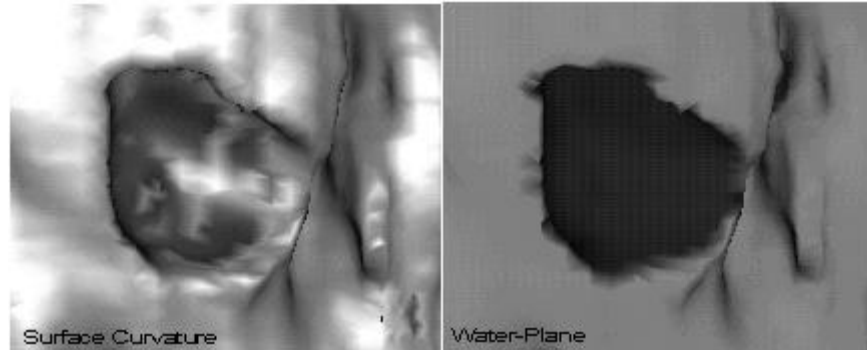

Figure 7: Complete and continuous regions

In addition, our method avoided false positive detections. In particular, the surface curvature method tends to falsely identify haustral folds as polyp candidates shown in Fig. 8.
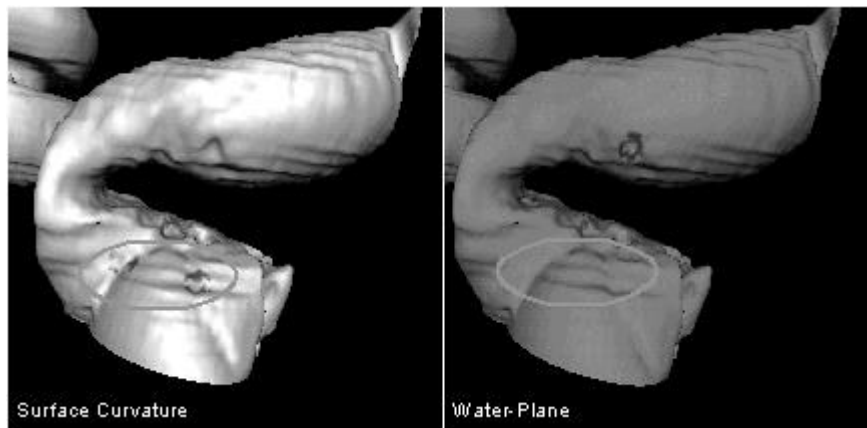

Figure 8: Omitted false detections

4. CONCLUSIONS AND FUTURE WORK

Overall, the water-plane method proved more robust and accurate in reporting polyp candidates than the surface curvature method currently in the CTCCAD software pipeline. The future integration of our algorithm into the CTCCAD software pipeline will enable better polyp candidates to be assessed, enabling higher sensitivity and specificity in true polyp detections.

ACKNOWLEDGEMENTS

REFERENCES

1. **http://www.cancer.gov/cancertopics/pdq/screening/colorectal/HealthProfessional/page2**

2. Winawer SJ, Zauber AG, Ho MN, et al. Prevention of colorectal cancer by colonoscopic polypectomy. N Engl J Med 1993;329:1977-81.